LHCf: Luminosity monitoring and measurement

Takashi SAKO
for the LHCf Collaboration
CONTENTS

Brief introduction to the LHCf (physics & detector)

Relative Luminosity measurement (single event, double arm, \( \pi^0 \))

Background (beam-gas)
Problems in the high-energy CR

• Existence of the GZK cutoff (extla Galactic)
  Cosmic microwave background prevents CRs of >$10^{20}$eV from traveling over 20Mpc
  Cutoff in the energy spectrum is expected.

• Chemical composition (Galactic <$10^{18}$eV)
  Acceleration limit will be determined by rigidity ($\propto p/z$).
  Maximum energy depends on $z$
  CR composition must change at around acceleration limit.
Existence of cutoff is not clear.

If no cutoff, exotic solutions will come out.

AGASA reports 18% systematic uncertainty in energy determination.

10% of systematic is due to interaction model.

Huge experiment (Auger, TA) will solve the statistics, but not for interaction model.

Accelerator calibration is necessary.
Forward (zero degree) measurement at TAN Recombination chamber at 140m from IP. Beam pipes are separated into two in the TAN by 96mm. Most of the HE secondary neutral particles enter in this gap. Beam pipes are separated into two in the TAN by 96mm. LHCf acceptance.
Model discrimination at 7 TeV

\[ \theta \sim 0 \text{ radian} \quad \text{and} \quad \theta \sim 270 \mu \text{ radian} \]

Gamma-ray spectrum at the neutral center and off-center expected from two models. \(10^7\) inelastic scat. is supposed.
LHCf Detector

Position sensitive shower calorimeters in the TAN

Arm#1

Two shower calorimeters (44 rl)
Tungsten & 16 plastic scintillators
SciFi hodoscope

4cmx4cm, 2cmx2cm

Scintillation light read by 32 PMTs
SciFi light read by 8 MAPMTs

Scintillators and PMTs are connected by optical fibers (not drawn)
LHCf Arm#1 & Arm#2

Detectors at either side of the IP1

Silicon $\mu$ strip instead of SciFi
Final assembly finishes in April
Photo of 15-Jan-2007

IP1 is 140m away
Just to understand scaling...
LHCf “Event”

- BC identification by two BPTX signals (level1)
- $>100\text{GeV}$ shower identification in any 1 of the calorimeters ($>10\text{GeV}$ at $450\text{GeV}$) (level2)
  \[
  \Rightarrow \quad \text{single event}
  \]
- Two gamma-ray showers in a single detector
  \[
  \Rightarrow \pi^0 \text{ decay gammas}
  \]
  (available only at 7TeV run)
- Coincident showers in the two detectors
- Front counter (in preparation)
LHCf operation plan

- LHCf detector & electronics require >2 \(\mu\) sec event separation
  \(\Rightarrow\) operation at 43 bunch.
- <1kHz DAQ rate
  \(\Rightarrow\) moderate upto \(L=10^{29}\) cm\(^{-2}\)sec\(^{-1}\)
  radiation weak; \(\sim0.5\)y lifetime @\(L=10^{30}\)
  several hours operation for science

LHCf measures the relative luminosity in the commissioning phase.
Absolute normalization in future with RP
Single event rate

- @L = $10^{29}$ with $\sigma_{\text{inel}} = 100\text{mb}$, collision rate = $10^4$/sec

I use these numbers in this talk. Event rates are scalable in L except for offline information.

- Aperture of the LHCf;
  - ~0.1 single event / collision @ 7 TeV (event rate ~1kHz = DAQ limit)
  - ~0.002 single event / collision @ 450 GeV (event rate ~20Hz) ⇒ discuss later
Particle in front of the TAN

7TeV

Particle Map (> 100GeV)

450GeV

Particle Map (> 5GeV)

Number flux

Energy flux
Resolution of the neutral center determination (7TeV run, offline)

- 10^6 inelastic interactions ~100 sec at L = 10^{29} cm^{-2} s^{-1}
- Using a simple peak finding analysis
- 0.1 mm resolution is obtained

SciFi intensity map for decentered collision (cross; simulated neutral center)
Event rate summary for 7 TeV run (relative luminosity monitoring)

- Single event rate; \( \sim 1 \text{kHz} \) @ \( L = 10^{29} \text{cm}^{-2}\text{s}^{-1} \)
- Double arm coincidence (10% \( \times \) 10% = 1% aperture \( \sim 100 \text{Hz} \)) is powerful to reduce beam-gas, beam halo background.
- Pi0 mass reconstruction also reduces the background with 1% aperture (100Hz; offline)
- Position resolution for the neutral center (offline)
Front Counter (in preparation)

To overcome the small aperture in the 450GeV run

Double layer thin plastic scintillator
80mm × 80mm

⇒ 0.02 events/collision @ 450GeV run

1 r.l. of the beam pipe converts neutral particles (mainly gammas) into charged particles.
Event rate summary for 450GeV run (relative luminosity monitoring)

- Single event rate; 20Hz@L=10^{29}
- Single event of the front counter; 200Hz
- Position dependence ... unable
- Double arm coincidence of front counter (~2%×2%=0.04%) 4Hz
- Pi0 reconstruction ... unable
- Model dependence (science goal)
Model discrimination at 450 GeV

Expected gamma, neutron spectrum at $10^6$ inelastic interactions
Incident on detector
It corresponds to $\sim 100$ sec at $L=10^{29}$ cm$^{-2}$s$^{-1}$.
Detector response, analysis not included.
BG for relative lumi measure

• Beam-gas collision
  \( R_{\text{collision}}/R_{\text{gas}} \) depends on the vacuum condition and the beam optics.

  with \( N_{\text{H}_2\text{equiv}} = 4 \times 10^{12} \text{ m}^{-3} (*) \), ratio is <0.01 at the worst estimate in the LHCf operation

### Performance at 450 GeV

<table>
<thead>
<tr>
<th>Parameter</th>
<th>IH</th>
<th>LH</th>
<th>IH</th>
<th>LH</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_b$</td>
<td>43</td>
<td>43</td>
<td>156</td>
<td>156</td>
</tr>
<tr>
<td>$i_b \times 10^{10}$</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>10</td>
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<tr>
<td>$\beta^* \times 15$ (m)</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Intensity per beam</td>
<td>$8.6 \times 10^{11}$</td>
<td>$1.7 \times 10^{12}$</td>
<td>$6.2 \times 10^{12}$</td>
<td>$1.6 \times 10^{13}$</td>
</tr>
<tr>
<td>Beam energy (MJ)</td>
<td>.06</td>
<td>.12</td>
<td>.45</td>
<td>1.1</td>
</tr>
<tr>
<td>Luminosity $\times 15$</td>
<td>$2 \times 10^{28}$</td>
<td>$7 \times 10^{28}$</td>
<td>$2.6 \times 10^{29}$</td>
<td>$1.6 \times 10^{30}$</td>
</tr>
<tr>
<td>Event rate $\times 15$ (kHz)</td>
<td>0.7</td>
<td>2.8</td>
<td>10</td>
<td>65</td>
</tr>
<tr>
<td>W rate $\times 15$ (per 24h)</td>
<td>0.8</td>
<td>3</td>
<td>11</td>
<td>70</td>
</tr>
<tr>
<td>Z rate $\times 15$ (per 24h)</td>
<td>0.08</td>
<td>0.3</td>
<td>1.1</td>
<td>7</td>
</tr>
</tbody>
</table>

1. Assuming 450 GeV inelastic cross section $\sigma_{\text{inel}}$ = 40 mb
2. Assuming 450 GeV cross section $W \rightarrow l\nu$ = 1 nb
3. Assuming 450 GeV cross section $Z \rightarrow ll$ = 100 pb
Beam-gas event at 450 GeV

- Gas pressure is estimated to be $10^{-8}$ Torr (R. Bailry, 2006)
- $10^{-8}$ Torr corresponds to $2 \times 10^{15} \text{H}_2/\text{m}^3$
- Beam-gas event rate, comparable to the collision event rate.
- Gas distribution is necessary for detailed estimation
- Double arm (front counter) coincidence
- Estimation before collision
Conclusion

- LHCf can measure relative luminosity at the commissioning phases.
- 1kHz(@7TeV) and 20Hz(@450GeV) single event rates are expected.
- Double arm event and Pi0 reconstruction (offline, 7TeV only) are useful to eliminate beam-gas BG.
- Front counters raise the event rates.
- Position resolution helps neutral center monitoring (offline, 7TeV only).
Event classification

a, b, c are proportional to luminosity, but not d. Double arm coincidence is necessary to eliminate d.
Pi0 mass reconstruction

![Graph showing Pi0 mass reconstruction with various data points and labels.](image)
Effect on BRAN

Same interaction length for copper bars and LHCf towers
Particle distribution in BRAN as a function of beam center

Out of LHCf; Gamma-ray showers developed in the beam pipe and BRAN itself

Full MC with beam-pipe, LHCf, BRAN
The ratio of particles detected by the 4 parts of the BRAN detector.
The threshold of BRAN is set at > 500 particles.
Position identification by the LHCf